WOODS HOLE OCEANOGRAPHIC INSTITUTION
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April 16, 1998

Dr. Steven G. Ackleson
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Dear Dr. Ackleson:

Per the Reports and Distribution Attachment #1, located in the ONR grant document for Grant No. N00014-95-1-0333, please find enclosed three copies of a progress report and Form SF-298 which was prepared by Dr. Heidi M. Sosik.

Copies of this form and the report have also been distributed to the other addressess listed in Attachment Number 1.

Sincerely,

Jane E. Marsh

Jane E. Marsh
Senior Staff Assistant
Biology Department

xc: Administration Grants Officer, ONR, Boston (SF-298 Form only)
Director, NRL (1 copy w/SF-298)
DTIC, Ft. Belvior, VA (2 copies w/SF-298)

RESPONSE OF PARTICULATE OPTICAL PROPERTIES TO COASTAL MIXING PROCESSES

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LONG TERM GOALS

Our long-term goals are to develop a better understanding of the relationships between upper ocean optical properties and particulate and dissolved seawater constituents, and to determine how these relationships are influenced by physical processes. Specific long term objectives include both predicting and modeling optical variability relevant for biological processes, such as phytoplankton photosynthesis, and retrieval of information about the biomass and activity of plankton from optical measurements.

OBJECTIVES

Spatial and temporal variability in particulate and dissolved material is a significant source of optical variability in the upper ocean. The primary objective of the present work is to examine the interaction between physical processes and the properties, abundance, and optical significance of different particle types in coastal ocean waters. Specific project objectives are to refine individual particle measurement methods and develop approaches to using individual particle results for interpretation of both inherent and apparent bulk optical properties (IOP/AOP). The project comprises a combination of instrument development and field studies in coastal waters of the eastern US continental shelf.

APPROACH

The approach we have taken employs techniques for characterizing and assessing the optical properties of particles, using both *in situ* and ship-board instrumentation and both bulk and single particle methods. Our primary tools are flow cytometry for assessing individual particle light scattering and fluorescence properties, spectrophotometry for measuring bulk dissolved and particulate absorption spectra (including separation of phytoplankton pigment absorption from the bulk absorption via methanol extraction), and spectral underwater radiometry. Our goal is to conduct flow cytometric and spectrophotometric measurements both on discrete water samples and with in situ instruments. In situ measurement provides the opportunity for relatively unperturbed sampling, with generally greater spatial resolution, while analysis of discrete water samples continues to allow more detailed characterization of optically-active seawater constituents. We have employed our sampling methods during the Coastal Mixing and Optics (CM&O) field study in continental shelf waters south of Cape Cod, MA (40° 30′ N 70° 30′ W).

WORK COMPLETED

During the past year, we have completed our participation in the CM&O field experiment. This included taking part in four cruises and analyzing samples collected on a fifth. Our sampling was most intensive on the two main optics cruises to the experiment site (R/V Seward Johnson cruise 9610, August 17 - September 7, 1996; R/V Knorr cruise 150, April 23 - May 13, 1997), but was also conducted on several of the interim mooring turn-around cruises (R/V Oceanus cruise 288, September 25 - 28, 1996; R/V Oceanus cruise 295, January 5-7, 1997; R/V Knorr cruise 149, April 16-17, 1997). Our primary sampling objectives on these cruises included characterization of optically active particles, assessment of absorption and scattering properties of particulate and dissolved material (including size dependence for particles), and measurement of apparent optical properties. Our sampling was conducted to evaluate vertical and some scales of temporal variability.

We have completed preliminary analysis of most of the data collected during the during the field experiment and have begun to examine patterns and scales of observed variability. We are currently attempting to characterize levels of variability in optical properties between and within the 3-week intensive sampling periods in late summer 1996 and spring 1997 and relate these to biological, physical and chemical processes which affect optical properties.

RESULTS

We have completed a descriptive analysis of optical and particle variability observed during the field experiment, including AOP and flow cytometry results collected by our group and some IOP data provided by C. Roesler, R. Zaneveld and S. Pegau (IOP data are not shown in the present report). These results are briefly summarized here.

August/September 1996 - In late August, the water column was consistently stratified with a persistent subsurface maximum in the concentration of phytoplankton pigments (see Fig. 1) which was associated with peaks in absorption and scattering coefficients for particles. There were corresponding subsurface peaks in diffuse attenuation coefficients at blue-green wavelengths. Concentrations of picophytoplankton and nano/microphytoplankton showed strong vertical dependence, with the smallest cells highly abundant ($>10^5$ cells ml^{-1}) at depths just above the pigment maximum and the larger cells present throughout the upper 30 m, but at approximately 10-fold lower levels. These conditions were dramatically disrupted by the passage of hurricane Edouard through the study site during the first days of September. Upon our return to the site after the hurricane, pigment and phytoplankton cell concentrations had fallen precipitously and optical properties were mainly dependent on resuspended particulate material.

April/May 1997 - During the spring cruise, stratification was weaker than during the previous August and some mixing or advective events occurred during the first half of the cruise (see Fig. 1). In contrast to the first cruise, picophytoplankton abundances were very low and maxima in phytoplankton pigment concentrations and cell abundance were found in the surface layer. This vertical distribution of phytoplankton was associated with surface layer maxima in absorption, scattering and diffuse attenuation coefficients. The latter half of the sampling period was characterized by weak but persistent stratification which was associated with a phytoplankton bloom in the surface layer, with increases in particle absorption and scattering and in diffuse attenuation. Interestingly, the period of highest pigment concentration during this period (days 126-128) was associated with relatively low phytoplankton cell concentrations.

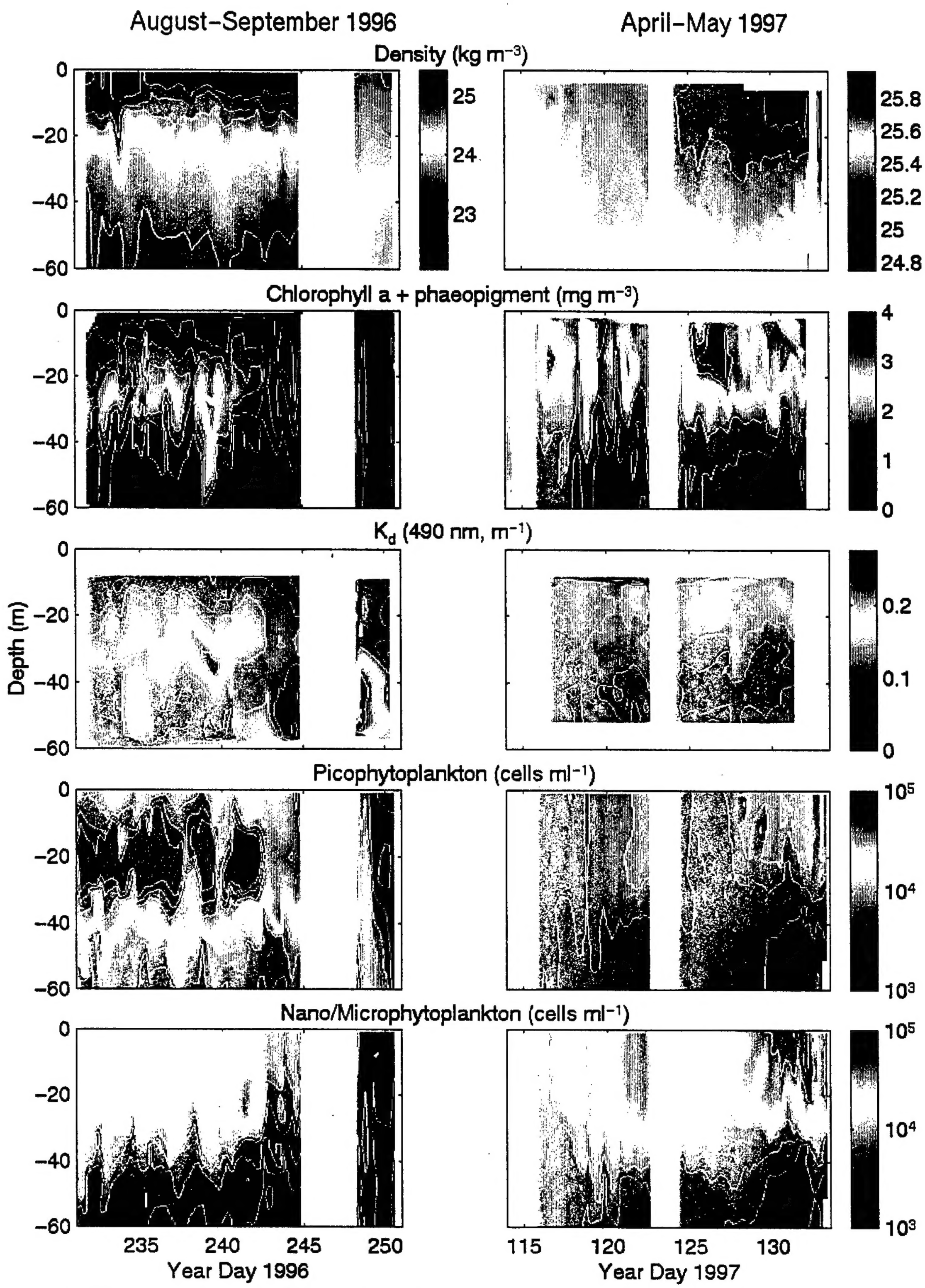

Figure 1. Time series of depth profiles observed during intensive sampling conducted at 40° 30′ N 70° 30′ W during late summer 1996 (left panels) and spring 1997 (right panels). Panels top to bottom: Density, chlorophyll a + phaeopigment concentration (data provided by Dr. Collin Roesler, U. Conn.), diffuse attenuation for downwelling irradiance at 490 nm, picophytoplankton (genus *Synechococcus)* cell concentration, nano/microphytoplankton cell concentration.

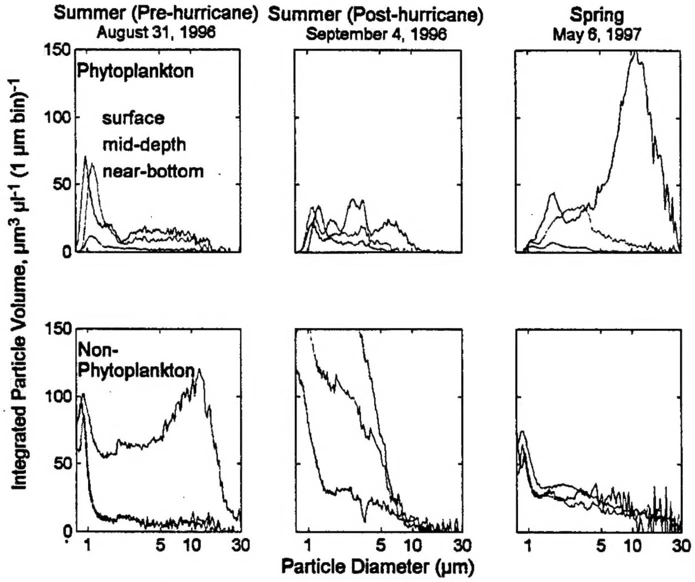

Figure 2. Selected examples from >1000 size distributions of phytoplankton and non-phytoplankton particles estimated from flow cytometric measurements of forward light scattering by particles in 5-ml water samples.

Optically active particles were found to be highly variable during the experiment. Some of the most dramatic changes were associated with passage of the hurricane, which resulted in a decrease in abundance of picophytoplankton and an increase in larger (>2 µm) cells (Fig. 2). Before the hurricane, non-phytoplankton particles were major contributors to particle volume only near the bottom, but afterwards they dominated in the chlorophyll maximum layer as well. The non-phytoplankton particles were smaller after the hurricane, with few particles > 10 µm present. In the spring, picophytoplankton were much less abundant than in summer, and there was a bloom of >10 µm cells at the surface. Non-phytoplankton particles in the upper water column were more abundant in the spring than in the pre-hurricane summer samples, but the spring surface bloom of large phytoplankton cells was not reflected in an increase in other large particles.

Time series of mean phytoplankton properties show diurnal variations associated with cell growth and division patterns and larger scale changes related to a combination of physical processes and physiological acclimation (Fig. 3). The largest and most highly pigmented cells were usually found below the mixed layer in summer, while in spring they sometimes occurred near the surface. The cells which reached highest abundance (see Fig. 1) were relatively small (low scattering cross-section) and had little pigment (low fluorescence). Towards the end of the sampling period, bulk pigment concentrations declined slightly as cell concentrations increased; mean cellular fluorescence and forward scattering cross-section declined during this period. We are currently exploring the significance of these changes in particle properties for interpreting optical signatures during this period.

Current work focuses on complete characterization of the size and relative abundance of phytoplankton and other 1-50 µm particles. Based on flow cytometry, we have estimated size distributions for phytoplankton, including size dependence of forward angle light scattering and absorption (488 nm), and are refining our estimates of size and light scattering by other particles (see Fig. 2). These results will be used to quantify the role of different sizes and types of particles in regulating the bulk optical variability observed in situ (e.g., what fraction of the total absorption and scattering is due to picophytoplankton as a function of depth and time?).

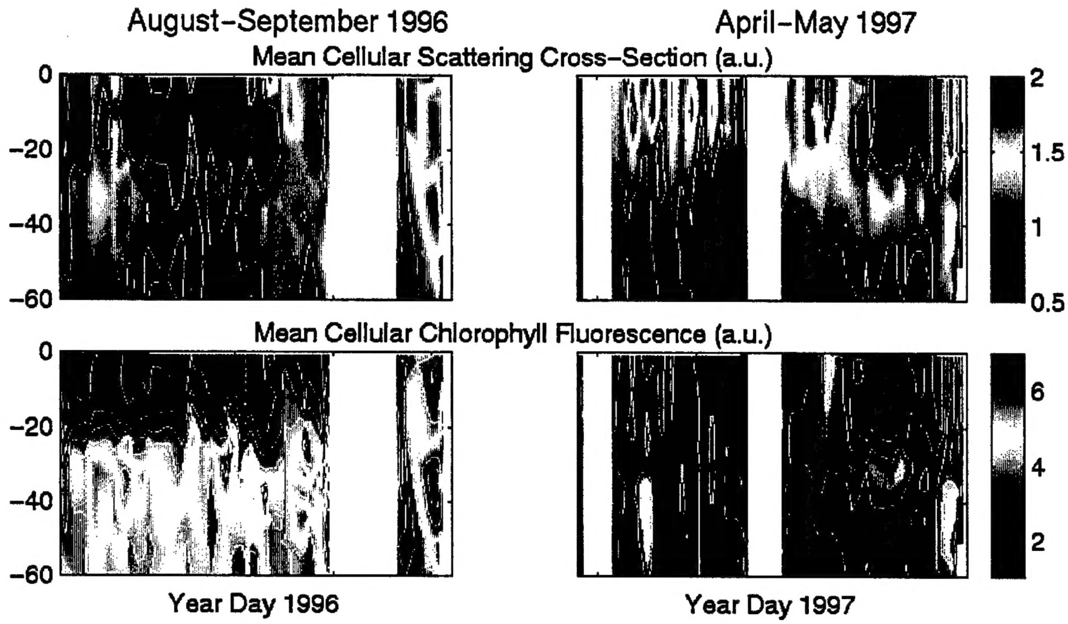

Figure 3. Mean scattering cross-sections (forward angles ~3-20°) and chlorophyll fluorescence per cell for nano- plus microphytoplankton as measured by flow cytometric analysis.

distributions for phytoplankton and non-phytoplankton particles is a new contribution which will lead to better understanding of optical variability in the ocean.

TRANSITIONS

We have several on-going collaborations with other investigators participating in the CM&O program. Our results from sampling on mooring-turnaround cruises are being used by Dr. Tommy Dickey's group at UCSB for interpretation of the observations from moored sensors. Radiometry results from the main optics cruises have been provided to Dr. Ron Zaneveld at OSU and used in a study of the relationship between diffuse attenuation for irradiance and absorption and scattering coefficients for a variety of environments (Zaneveld et al. subm.). It is anticipated that collaborations involving exchange of results with other CM&O groups will continue to expand in the near future.

RELATED PROJECTS

This project is closely tied with a NASA New Investigator Program award (Sosik) for investigating the regulation of local biological production of particles at the CM&O site and to explore the effects of changes in particle properties on ocean color. In addition, Olson is independently funded (DOE, NSF) to develop an in situ flow cytometer. The interpretation of flow cytometric light scattering and fluorescence distributions is also being supported by a NSF JGOFS project for work in the Arabian Sea (Olson).

REFERENCES

Zaneveld, R.V., S. Pegau, et al. The determination of profiles of the attenuation coefficient of irradiance and euphotic depth from absorption and attenuation coefficient profiles. Submitted to Limnol. Oceanogr.

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13. Abstract

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